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GEOLOGICAL HISTORY OF THE CHARLES RIVER.

BY FREDERICK G. CLAPP.

[Concluded from page 201.]

TERTIARY HISTORY OF THE CHARLES RIVER SYSTEM.

HAVING deciphered the geography of the region included in the present basin of the Charles River as it was at the beginning of the Pleistocene period, let us now endeavor to verify the results obtained by going back to the Tertiary period and showing how the Pleistocene streams could be developed from earlier ones. As this period is more remote and of comparatively long duration, and as the relics of many of the old valleys have long since disappeared, it is obviously impossible to trace in detail the changes during that time. The best that can be done is to show the most probable changes that could bring about Pleistocene conditions.

I have shown that at the beginning of the Pleistocene period the present Charles River was not in existence; but instead, the region was drained by a number of streams of varying importance, coinciding to a considerable degree with the geological structure. The region west of Medway was drained by two main streams flowing south to join the Blackstone in Rhode Island; the Populatic flowed south from Holliston, and also joined the Blackstone, but farther east; the Baggistere had its source near the head of the Populatic, but flowed

FIG. 14. — DUDLEY POND; SITE OF BURIED VALLEY BETWEEN THE SUDBURY AND CHARLES RIVERS.

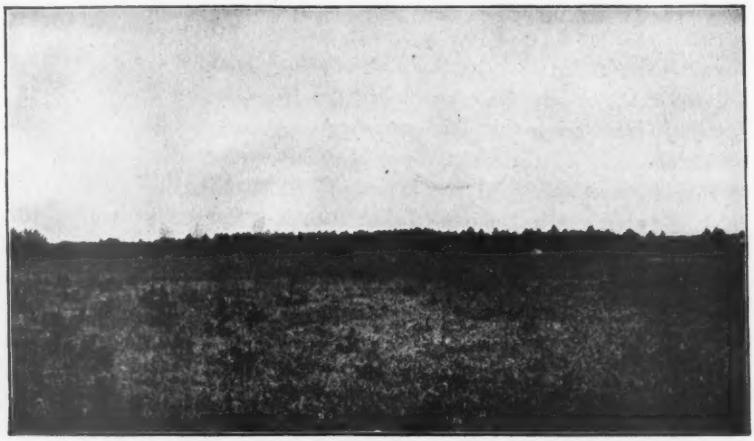

FIG. 15. — SAND-PLAIN BETWEEN PICKEREL AND JENNINGS' PONDS; SITE OF BURIED VALLEY BETWEEN THE SUDBURY AND CHARLES RIVERS.

in the opposite direction, to the Neponset, which at that time followed approximately its present course to the sea; the Merrimac flowed southeast from Lowell to Boston Bay; the region north of Dedham and east of Needham was drained by an independent stream, probably a branch of the Charles; while the entire area now comprised in the Sudbury and Assabet basins was tributary to the Charles, and thence to Boston Bay.

To attain these conditions complex developments were necessary, although the changes were probably not so momentous as those shown by Professor Crosby to have taken place in the case of the Nashua River.

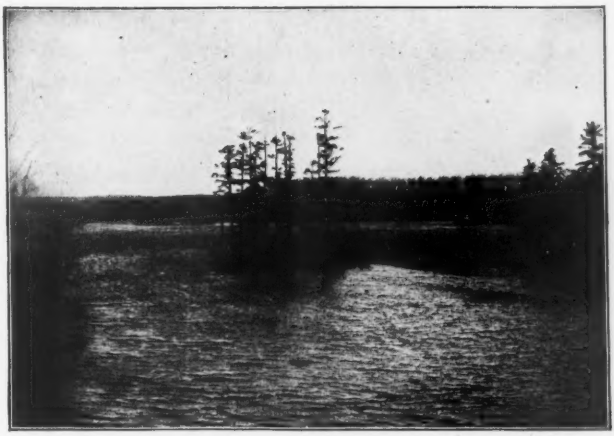

FIG. 16. — MORSE'S POND; SITE OF BURIED VALLEY BETWEEN THE SUDBURY AND CHARLES RIVERS.

The Charles differs from the Nashua in not having such a strongly marked and simple valley as the latter. Instead, it is a composite of several valleys. While with the Nashua the Tertiary changes were the greatest, in the Charles those of the Pleistocene period are found to be the most important. The Tertiary changes which did occur cannot, however, be neglected here.

When, at the close of the Cretaceous period, the recently formed peneplain was raised gradually out of the sea, its surface consisted of unconsolidated Cretaceous sediments which overspread the whole region, completely burying the underlying solid rocks. Evidently, there was a gradual upward slope inland, and the grade was increased

at the time the land was elevated. Therefore, upon this plain, sloping to the east and south, a drainage system must have been established following the normal seaward slope, and entirely independent of the structure of the underlying rocks. This original drainage system probably resembled more or less closely the present drainage of southern New Jersey. It would be useless to attempt to decipher the courses of these *oldest* streams. The last remnants of their valleys have long since disappeared, and they are as likely as not to have flowed at some points over the tops of our highest hills. Following the laws of development of streams, main trunks were formed into which flowed minor streams, all of which kept continuously at work wearing away the land. Thus, in a comparatively brief geological time, the Cretaceous sediments were entirely removed, and the streams became superimposed upon the pre-Cretaceous rocks of varying hardness, in which for a while they continued their work of erosion.

Remnants of some of the valleys formed in the succeeding epochs can be seen at present in numerous gaps in the highlands, at present unoccupied by large streams. One of these gaps, probably formed in early Tertiary time, is the marked line of valley which the old Middlesex Canal followed from Lowell to Boston, and which is the site of the early Pleistocene Merrimac. This is the most direct route to the sea for the Merrimac, and there is no necessity for supposing that at any time during the Tertiary period it took a different course. Another gap, of less extent, lies between Bear and Doublet hills, west of Waltham, having a minimum elevation of 160 feet, and making a pass two miles wide in the crystalline rocks forming the watershed of the Charles at this point. This pass is in line with a marked depression extending westward from Sudbury. Several miles south of this, across the watershed in the vicinity of Cochituate, is a third gap, which below the 200-foot contour is a mile and a half wide, and, like the one at Waltham, has a minimum elevation of 160 feet, the level of the sand-plain at this point. The topographical map shows that this gap is continued eastward through the present valley of the Charles between Needham and Dedham, and thence along Mother Brook to the Neponset River. Westward it is continued between Nobscot and Green hills to the valley of the Assabet. A fourth line of valley extends eastward from the vicinity of Sherborn through Millis, Walpole and Norwood, crossing the Charles-Neponset water-

shed at the level of the 160-foot sand-plain. The high ridge extending north from Bellingham has been already noted. Both east and west of this are north-south valleys, pointing towards prominent gaps in the southern watershed: one at South Milford, two miles wide between the 300-foot contours; the other east of Bellingham, and a mile wide. Each of these gaps is in a direct line with the corresponding portion of the Charles to the north, and probably marks the site of a Tertiary outlet towards Narragansett Bay. As one coincides exactly, and the other closely, with the outlet at the beginning of the Pleistocene period, the streams occupying them, like the Merrimac, probably did not change their courses greatly during Tertiary time. South of the height of land across Foxsboro, Wrentham and Franklin, all drainage was to the south. The streams which formed these various gaps are the earliest of which any traces remain, and represent that epoch when the Tertiary system of drainage had become firmly established in the pre-Tertiary formations.

Some of the streams of that time, like the Merrimac, and the Milford and Medway branches of the Blackstone, maintained their courses until the Pleistocene period. They flowed across formations of varying hardness, but, being beyond the influence of more powerful neighboring streams, were not diverted from their courses. For instance, the river crossing the Cochituate watershed to the Charles, coming from an area of hard crystalline rocks, crossed the softer formations in Wellesley and Needham, then flowed over the crystalline area east of Needham, reaching the sedimentaries again in Hyde Park (Plate 1, facing page 172). It is possible that this stream may be the lower portion of the Wachusett River[1] discovered by Professor Crosby, who has traced its course as far as the Assabet. The discovery of an ancient river flowing from the Assabet to the sea makes it a reasonable supposition that the two were synchronous, and hence probably the same. This stream, coming from a long distance, and having many tributaries, must have carved out a broad valley, and appropriated the drainage of a considerable area. The upper portion of the Sudbury and its tributaries belonged to this system. The valley of the Sudbury north of Cochituate is certainly very old, and was probably formed at that time. Being tributary to the powerful trunk stream, it could erode its valley rapidly, cutting below the level of the Waltham gap, and beheading

[1] W. O. Crosby: Geological History of the Nashua Valley. TECHNOLOGY QUARTERLY, XII, p. 312.

the stream occupying it. The lower portion of this beheaded stream is represented today by Stony Brook, which has never been of sufficient size to make a large valley. One of its branches, the infantile Charles, flowing northward from Needham through the Boston basin, cut backward toward the south, and on account of its location on the softer rocks, deepened its valley below that of the east-west stream (the possible Wachusett). This river was retarded in its erosion by the crystalline areas across which it flowed, making possible its capture by the Charles. Thus, except for several minor tributary streams, the Tertiary valley between Wellesley and Hyde Park was left dry. The valley northeast of Needham was probably formed by a tributary to the Charles which cut backward from Highlandville along the slate belt to the east.

The other great Tertiary stream draining the area under consideration was the Baggistere, which rose in the vicinity of Holliston, and flowed east as far as Norwood; thence it either maintained its eastward direction to the sea along the southern border of the Blue Hills, or else turned slightly to the north, reaching Boston Bay through the Neponset Valley, along the north side of the range. If it ever flowed on the south side of the Blue Hills it cannot have done so for any great length of time; for, flowing across the crystalline rocks between the Norfolk and Boston basins in the vicinity of Braintree, its down-cutting must have been retarded, giving the drainage of the Boston Basin an opportunity to cut back southward along the sedimentary belt west of the Blue Hills and to capture the Baggistere.

Whether or not such a capture took place, the Neponset Valley, as is shown by its great size, was at an early date occupied by a large stream. The Neponset River, flowing entirely upon the sedimentary rocks, was able to cut back its valley for a considerable distance, the limit probably being reached in the vicinity of Norfolk, where, as indicated by the topography, a tributary of Narragansett Bay had its source. At first the south-flowing streams in this vicinity may have run directly across the crystalline area between the Norfolk and Narragansett basins; but in time they must all have been diverted to the easier outlet through the connecting pass at Wrentham. Thus the Norfolk basin became occupied by two main streams, flowing in opposite directions from the watershed at Norfolk. The minor streams having their sources on the large crystalline area to the north then so adjusted themselves as to take the most direct courses to the

main streams in the basin. It is probable, however, that little adjustment was necessary, as the basins lay directly across their seaward paths.

It certainly does not appear that any simpler sequence of events than those outlined above could have brought about the conditions which existed at the beginning of the Pleistocene period, and undoubtedly the Tertiary changes were much more complex. But we have found that the preglacial streams deduced from present conditions correspond closely with those derived from the most probable development of the Tertiary drainage.

Lake Charles.

At the beginning of the Pleistocene period occurred the great elevation of the land which is regarded as the cause of the great Ice age, during which a mantle of bowlder clay, or till, was spread over the surface of the land. As the till, in most places, makes but a thin covering over the underlying rock, an occurrence of the former is usually a fairly good indication that rock exists at no great depth below. This is not a necessary conclusion, however, for valleys have frequently been found which are filled with till to a considerable depth. And in some cases drumlins lie directly in the path of a preglacial valley or gorge. As examples in this region we have Milton Hill in Milton, and Fairmount in Hyde Park. Either North Hill in Needham or the drumlin just east of Wellesley must also overlie a buried gorge.

With the subsidence of the land at the close of the Glacial epoch came the melting of the ice-sheet and the release of great volumes of water, which collected south of the receding ice-front in glacial lakes. In basins where the preglacial drainage had been to the north, the water-parting on the south naturally formed the southern barrier of the glacial lake. But in the basins of the Upper and Middle Charles the greater part of the preglacial drainage was southward. In these cases, at times when the ice-front rested at narrow portions of the south-sloping valleys, the detritus-laden streams from the ice-sheet formed apron-plains of sand and gravel, which completely closed the valleys and presented an effectual southern barrier to the glacial lake.

Lake Charles, being retained on the south by the frontal plains and the intervening highlands, and on the north by the high ice-front,

necessarily overflowed through the lowest pass in its southern water-parting. As the ice receded northward, lower and lower passes were uncovered in the southern and eastern sides of the basin, serving as successive outlets for the lake, and allowing the water to fall each time to a lower level. Each stage of the lake is characterized by extensive deposits of modified drift, the maximum elevation of each coinciding approximately with the level of the lake during that stage.

Bellingham Stage. — During its history, Lake Charles had twelve distinct outlets, two of which coincided with outlets of glacial Lake Neponset (Plate 4). The stages are less in number than the outlets, however, for during the earlier history of the lake each stage had several outlets at or near the same level. Thus the two outlets in the vicinity of Bellingham and those southeast of Franklin have all an elevation of about 240 to 260 feet, as shown by the contours. The stage of the lake corresponding to these outlets may be called the Bellingham stage.

The shore line of the lake at this time was in the vicinity of the 260-foot contour, and extended up the main valley as far as Milford, and up the valley of Hopping Brook two miles beyond Braggville. Down the valley it extended to near North Bellingham. Bear Hill and several smaller prominences rose as islands in the lake. The greatest depth of water was about 60 feet, in the vicinity of Crimpville. The outlet showing the best developed frontal plain is about half a mile wide, and situated midway between Unionville and Bellingham. At this point the steep and irregular ice-margin can be seen on the north, while in the other direction there is a long gradual slope to the southward. During this stage the water of the lake reached the sea through the Blackstone by way of Abbot's, Peters' and Mill rivers.

South of Franklin, at the margin of the area occupied by the Bellingham stage, and about 80 feet above the level of the water at this time, is a small area of modified drift about a mile and a half long, with an elevation of over 340 feet. This area presumably marks the site of a marginal lakelet, which was formed while the valley to the south was still occupied by ice. It must represent the true beginning of Lake Charles. During the decline of the Ice age such marginal lakelets were numerous, most of them, however, being of small size.

Upper Stage
Charles-Nepigon Stage
Sudbury-Cheming-Nepigon Stage

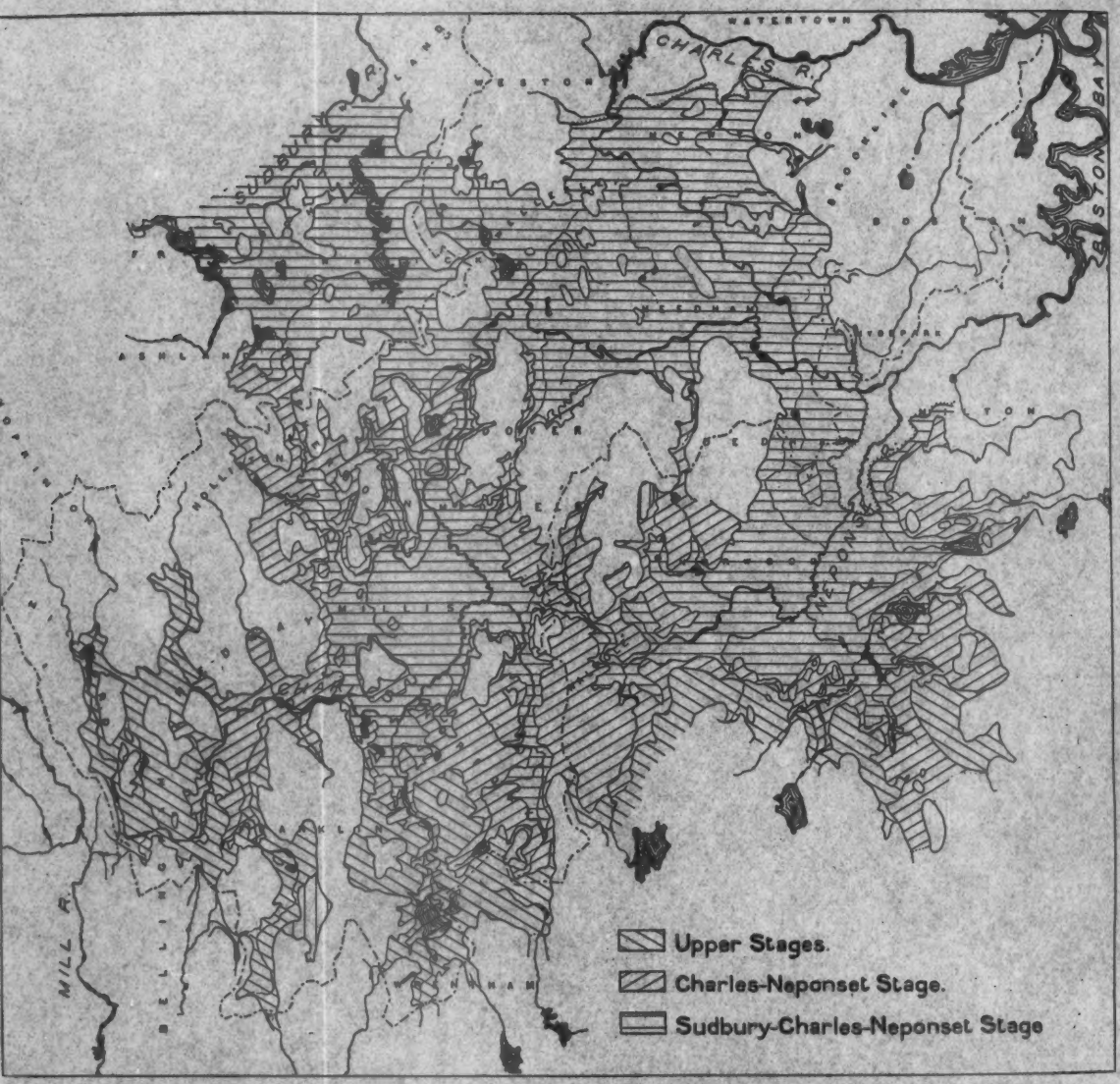

PLATE 4.—MAP SHOWING CHANGES IN GLACIAL LAKE CHARLES; ALSO PORTIONS OF LAKE SUDBURY AND LAKE NEPONSET. Scale, 1:250,000. (After unpublished maps by Professor W. O. Crosby, illustrating distribution of the drift deposits.)

Wrentham Stage. — Simultaneously with the Bellingham stage was the Wrentham stage, during which the ice in the region east of Franklin was disappearing. In this area there are four outlets, three of which are south of Whiting Pond, and the fourth just south of the Pinnacle. According to the topographical map, these outlets vary in elevation between 240 and 280 feet; but, like the Bellingham and Franklin outlets, they should probably all be referred to a single stage of the lake, the average elevation of which was near the 260-foot contour. The drift deposits show that on the west the shore line extended north to the vicinity of City Mills, and on the east to the southern part of Norfolk. There were several islands, one east of Franklin, a second east of Marsh Pond, a third southeast of City Mills, and two small ones south of Whiting Pond. The best developed deposits, so far as observed, are the Wrentham plains. Whiting, Archer's and Marsh ponds are kettle holes in these plains. The valley of Mill Brook was occupied by a lobe of ice, as is shown by the fact that the deposits referable to the next lower stage extend as far south as Whiting Pond. Plate 4 shows that the northern boundary of the deposits of this stage has a northwest-southeast trend, indicating that this was the direction of the ice-front. The same is true of the deposits formed during all the later history of the lake, showing that the ice disappeared faster from the western than the eastern part of the region.

Charles-Neponset Stage. — The continued recession of the ice during the Bellingham and Wrentham stages finally opened a passage to the east along the north end of the ridge north of Foxboro, and Lake Charles then became confluent with Lake Neponset. Probably about the same time the gap at Medway was opened, and the portion of the lake to the west became connected with the main body of Lake Charles. The development of the Neponset lake had been going on simultaneously with Lake Charles, and the ice had by this time receded far enough north to open the Stoughton outlet, at an elevation of about 200 feet. This, being lower than any hitherto uncovered pass in either lake, became the sole outlet for the confluent lakes. During this stage Lake Charles-Neponset probably occupied its maximum area. The Stoughton outlet must have continued in use for a relatively long time, while the ice was receding from the large area between Norfolk and the northern part of Sherborn in the Charles basin, and between Canton and the Blue Hills in the

Neponset basin. A comparison of these areas (Plate 4) again shows evidence of a more rapid retreat of the ice in the west than the east.

The deposits of this stage extend below the 200-foot contour up the valley of the Upper Charles beyond North Bellingham, along Mine Brook as far as Unionville, and in the valley of Mill Brook into the basin of Whiting Pond. Northward they extend through the pass north of Holliston occupied by the Boston & Albany Railroad, nearly to South Framingham, and east of Sherborn to the vicinity of Farm Pond. The pass west of Snow Hill, in Dover, must have been occupied by a shallow arm connecting the main lake with a bay to the north, as is proved by the deposits of modified drift at this level in the valley of Trout Brook. From the Neponset basin an arm extended north from Norwood, across Westwood to beyond Fox Hill. The presence of 200-foot deposits west and north of Great Blue Hill shows that while this area was covered by water the Monatiquot outlet was still blocked by ice on the east. Between Walpole and South Walpole, on the divide between the Charles and Neponset basins, extensive sand-plains were deposited, blocking the preglacial valley. During this stage the greatest depth of water in the Charles basin was about 100 feet, in the vicinity of Medfield, and in the Neponset basin, nearly 140 feet. Noon, Nason, Paul, Pine and Castle hills, besides many smaller areas, formed islands.

Sudbury-Charles-Neponset Stage. — With the disappearance of the ice from the valley of the Monatiquot River, an outlet was opened along the south side of the Blue Hills, at a level of about 160 feet, allowing the lake to overflow to the east, into Lake Bouvé,[1] which at that time had a level of about 120 feet. During this stage the Charles and Neponset lakes were confluent at two points: first, through a narrow pass, perhaps not over 500 feet wide, between the valley of Mine Brook in Walpole and Stop River in Medfield; and second, at Dedham, where the pass was nearly two miles wide. Lake Charles was also confluent with Lake Cochituate and Lake Sudbury. The water overflowing through the Monatiquot was not only that due to the melting of ice in the Charles-Neponset region, but also that of a large area to the west. At this time the ice-front in the Nashua Valley probably stood in the vicinity of Clinton, and the outlet of Lake Nashua was through the pass at South Clinton into the valley

[1] A. W. Grabau: Lake Bouvé. Occasional Papers, Bos. Soc. Nat. Hist., Vol. IV, Pt. 3, pp. 554–600.

of the Assabet River and thence to Lake Sudbury.[1] Thus the drainage of the entire area within the watersheds of lakes Nashua, Sudbury, Charles and Neponset was at this stage tributary to Lake Bouvé.

The plains at this stage of the confluent lakes are by far the best developed of any stage. The broad deposits in Medfield, Millis and Medway, as well as those in Wellesley, Needham and West Roxbury, were formed at this time. In Newton they are developed as far north as the Boston & Albany Railroad. Extending from Brighton westward along the line of the railroad into Weston is a well-developed ice-contact slope, which marks the northern limit of the lake at this stage. West of Needham and Sherborn the plains extend through Wellesley, Natick and Framingham, across the Cochituate water-parting to the valley of the Sudbury, where an extensive series of the same general elevation is found, extending even down the valley of the Concord River into Bedford and Billerica. Between Brighton and Hyde Park there is a satisfactory eastern land barrier for the lake (Plate 4), but the absence of such a barrier in the northern part of Newton, and again in Dedham, together with the characteristic ice-margins found in those places, indicates that while on the west the ice had retreated as far north as Billerica, it still occupied Boston Bay and a large part of the Boston Basin.

Lake Shawmut. — When the region directly north of the Blue Hills was finally uncovered, the passes in East Milton and West Quincy were opened, and the lake fell to still lower levels, first to about 70 feet, and later to about 50, corresponding to successive levels of Lake Bouvé. Still later the water stood at about 20 feet above the sea. Plains of these elevations are found in Newton, Waltham, Watertown, Boston, and in the valley of the Mystic River. To these lower stages of the combined lakes, entirely within the Boston Basin, Professor Crosby has given the name Lake Shawmut. To this body of water the lakes occupying the valleys of the Concord and Shawsheen rivers were tributary along the line of the Middlesex Canal and the ancient course of the Merrimac. When the ice finally retreated from the land on the southern side of Boston Bay, Lake Shawmut fell to sea level and disappeared.

Postglacial Development of the Charles River.

During the time when the ice was retreating from the region and the glacial lakes were falling successively to lower and lower levels,

[1] W. O. Crosby: Geological History of the Nashua Valley, *l. c.* p. 318.

new streams and drainage systems were gradually developing upon the land surface recently uncovered. The drift deposits had so changed the character of the topography, however, that the streams rarely resumed their former courses, the principal factor in reversing the drainage in the Upper and Middle Charles being the formation of the apron-plains which blocked the south-sloping valleys, and thus formed a new water-parting, north of which all drainage must be northward. As Lake Charles fell from stage to stage, all the outlets on the south and east were in turn abandoned, so that when the lake

FIG. 17. — LOOKING WEST, TOWARD SAND-PLAIN AT NEWTON LOWER FALLS, SHOWING EROSION-SLOPE ON NORTH SIDE OF RIVER.

finally completely disappeared from the basin of the Middle Charles, the new river had to take possession of the lowest outlet to the north, the pass midway between Medfield and Natick, through which it now flows.

North of Natick the new Charles reaches the valley of the old river, which, however, between Cochituate and Needham, has been blocked by the extensive sand-plains, forcing the new Sudbury to find an outlet to the north. The Charles, below South Natick, is forced to find a channel for itself along the southern border of the Needham plain, until it emerges, at Greendale, into another preglacial valley.

The circuitous course by way of Dedham, in place of the more direct one along Line Ditch, must have been caused by mere chance. Again, at Highlandville, the blocking of the preglacial valley by the sand-plain caused the river to deviate from its course, so that it now flows over solid rock at Newton Upper and Lower Falls, where it is still carving its gorges.

The characteristics of the drift deposits above the Upper Falls — irregular deposits, extending far out into the marsh — make it probable that there has been little postglacial erosion there. But at Newton Lower Falls the erosion slopes show that the sand-plain originally extended entirely across the valley, at a height of about 60 feet above the present river (Figure 17). When the stream first took this course, the plain acted as a barrier, which formed a lake between the Upper and the Lower Falls. In cutting down the outlet the present gorge was formed, and the river superimposed upon the bed-rock below, over which it now flows. During the development of the river several similar lakelets existed at different parts of its course.

Conclusion.

Having accomplished the first four of the five purposes stated in the introduction, it only remains for us to consider the fifth — to determine to what class of rivers the Charles belongs. Professor Davis has defined[1] several types, as follows: —

"An *original* river is one which first takes possession of a land area, or which replaces a completely extinguished river on a surface of rapid deformation.

"A river may be *simple*, if its drainage area is of practically one kind of structure and of one age. . . . It may be *composite*, when drainage areas of different structure are included in the basin of a single stream. . . .

"A *compound* river is one which is of different ages in its different parts. . . .

"A river is *complex* when it has entered on a second or later cycle of development."

We have already seen that our river taken as a whole is in a very youthful stage, having been formed by the filling with drift of several ancient valleys, formerly entirely distinct, and the development of their postglacial drainage into a single river system. Evidently,

[1] W. M. Davis: Rivers and Valleys of Penn., Nat. Geog. Mag., Vol. I, p. 218.

different portions must be placed in different classes, according to their respective histories. That portion between the source and South Milford is certainly *original*, but it is the only part of the river which *can* be called original. Certain portions taken separately are *simple*, but as a whole it is *composite;* for, as has been shown, such regions as those of the Middle Charles and the Boston Basin are entirely different in structure. Again, the river is *compound*, for its different parts differ greatly in age. As examples, may be noted the contrast between the topography of the Medway gorge and the valley of the Middle Charles, between the valley south of Needham and that north of the town, or between Hemlock Gorge and the basin to the southeast. All this shows that, throughout its course, the Charles is very *complex*. At several points it is a *superimposed* stream, as at Medway and again at Newton Upper and Lower Falls. Finally, as to whether it belongs with *consequent* or *antecedent* streams: — Powell has defined[1] the former as those whose courses are "consequent upon the constructional form of the land;" and the latter, as those which persist in their courses after a change by which others are destroyed. The Charles has entirely lost its *consequent* character. Parts of it, however, may be said to be *antecedent*, among these being the portion between Riverside and Boston, which occupies essentially its pre-glacial course.

From the foregoing general statements it is evident that the river as a whole cannot be placed in any one class, but that in studying it each portion must be classified according to its own characteristics. It is a stream occupying portions of several ancient valleys, which, having been obstructed by the drift of the ice age, have become connected by new channels, which now unite them into a single complex basin, in which flows the present peculiar and meandering river.[2]

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[1] J. W. Powell: Exploration of the Colorado River of the West, pp. 153, 163–166.

[2] The foregoing is the result of a thesis study done in the Geological Department of the Massachusetts Institute of Technology, and under the supervision of Professor W. O. Crosby.

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A LOGARITHMIC THREE-VARIABLE DIAGRAM FOR DATA OF THE FORM $a^m b^n c^p = k$.

ILLUSTRATED BY THE LAW FOR PERFECT GASES, $PV = RT$, WITH DIAGRAMS FOR VARIOUS GAS-ENGINE CYCLES.

BY HARRISON EVERETT ASHLEY.

GRAPHIC representation is the most successful way of preparing complex data for mental assimilation, and graphic processes displace many tedious calculations. The equilateral triangle, in which the sum of the perpendiculars from an included point to the three sides is a constant, has been used by Professors J. Willard Gibbs,[1] R. H. Thurston,[2] H. M. Howe,[3] C. R. A. Wright,[4] H. W. Bakhuis-Roozeboom,[5] W. D. Bancroft,[6] Hector R. Carveth,[7] F. A. H. Schreinemakers,[8] and others to show the variation of some physical property with variation in chemical composition of mixture of three chemical substances.

Professor Ernest A. Hersam[9] has shown very ingeniously how it may be used in the calculation of slags of three or four constituents. In the course of his discussion he says that a *right-angled triangle* may be used instead of the equilateral triangle, and "possesses some advantages in construction . . . . but the lack of symmetry and some other disadvantages make these departures generally less satisfactory for varied work."

[1] Equilibrium of heterogeneous substances. Trans. Conn. Acad. (1876), vol. iii, p. 176.

[2] Tensile strength of copper-zinc-tin bronzes. Proc. A. A. A. S., 1877.

[3] Heat of solidification of lime-alumina-silica slags. Trans. Am. Inst. Min. Eng. (1898), xxviii, 346. Also discusses a triangular pyramid for four variables.

[4] Limits of perfect miscibility of the eighty-four possible ternary alloys of lead, bismuth, zinc, aluminum, tin, silver, copper, cadmium, and antimony. Roy. Soc. Proc., **45**, 461; **48**, 25; **49**, 156, 174; **50**, 372; **52**, 11, 530; **55**, 130. J. S. Chem. Ind. (1890), 944; (1892), 245, 449, 492, 521, 693; (1894), 1014.

[5] Zeit. phys. Chem. (1894), **15**, 143.

[6] Jour. phys. Chem. (1897), **1**, 403.

[7] Melting-points of KNO_3-$NaNO_3$-$LiNO_3$ mixtures. Jour. phys. Chem. (1898), **2**, 209.

[8] Vapor pressure of ternary mixtures. Zeit. phys. Chem. (1901), xxxvi [3], 257.

[9] Trans. Am. Inst. Min. Eng. (1901), February.

Before seeing his paper, the writer of the present article had well-nigh completed a paper on "Slag Constitution, Studied by Means of the Tri-Axial Diagram with Rectangular Coördinates,"[1] in which the application was extended from the case $a + b + c = k$ to the more general case $ma + nb + pc = k$, where m, n, and p are any positive or negative, integral or decimal, real coefficients. The discussion was as follows:

"The tri-axial diagram is applicable only to the case of *three variables whose sum is a constant*, that is, to two independent variables. For example, if an alloy of tin, copper, and zinc be assumed to contain 15 per cent. of tin and 80 of copper, the percentage of zinc must be 5, the difference between 15 + 80 and 100. When the percentages of tin and copper have been fixed, that of zinc cannot be varied. But two independent variables can be shown by the common diagram with rectangular coördinates. A diagram showing only tin and copper percentages will serve to illustrate all the properties of the ternary

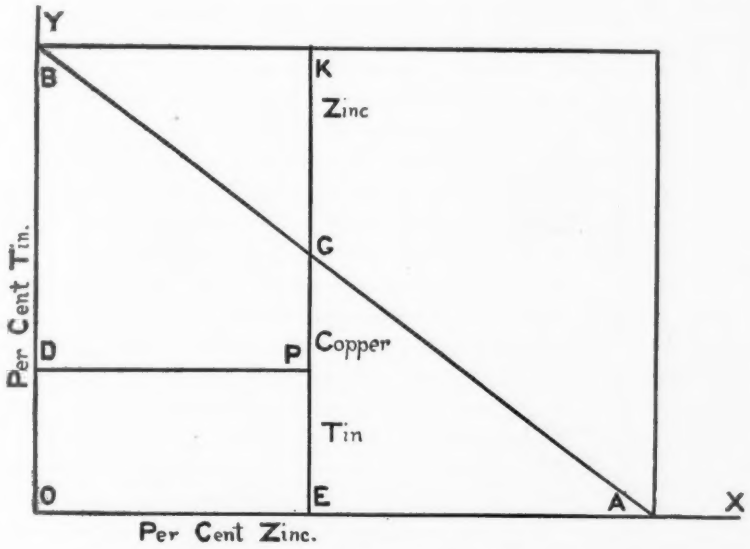

FIG. 1. — DERIVATION OF THE RECTANGULAR TRI-AXIAL DIAGRAM.

[1] Trans. Am. Inst. of Min. Engineers (1901), November.

bronze. Why use, then, the inconvenient oblique equilateral triangle diagram, when results can be plotted with comparative ease on ordinary cross-section paper, with rectangular coördinates, in an erect, right-angled triangle? Moreover, it is possible to read off from such a plot the third or dependent variable.

"In Figure 1, let any vertical line (as $EK = OB$) represent 100 per cent. of whatever mixture is under consideration, say tin-copper-zinc. Further, let the lower part (EP) of the line represent per cent. of tin, the upper part (GK) represent per cent. of zinc, and the middle part (PG), per cent. of copper. Then arrange the vertical lines along OX so that the abscissæ also shall represent the percentage of zinc, (*i. e.*, OE = percentage of zinc). We have now the per cent. of zinc represented by two separate means, one of which is superfluous; and we may accordingly dispense with the upper part of each vertical line, reducing the diagram from a rectangle to the triangle AOB. For any point P, the abscissa ($DP = OE$) represents per cent. of zinc; the ordinate ($PE = OD$) represents the per cent. of tin; and the distance along the vertical line (PG) to the hypothenuse AB represents per cent. of copper. The scales for the two quantities measured along the vertical lines are from the nature of the case the same, while the scale for the quantity measured by the abscissæ is the same as for the other two only in the case of the isosceles right-angled triangle. It is desirable to have all three variables plotted to the same scale.

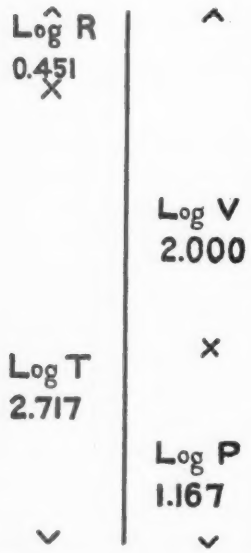

FIG. 2. — DERIVATION OF THE LOGARITHMIC THREE-VARIABLE DIAGRAM.

. . . . . .

"It is evident that the same principles may be applied to plotting data of the forms $a + b - c = k$ and $a - b - c = k$, or in general, of the form $ma + nb + pc = k$, where m, n, and p are any positive or negative, integral or decimal, real coefficients."

It soon occurred to the writer that this principle might be extended to data of the form $a^m b^n c^p = k_1$ by taking logarithms; thus

$m \log a + n \log b + p \log c = \log k_1 = k$, which is in the form already discussed. Since the logarithm of a variable factor may vary from $+\infty$ to $-\infty$, any logarithmic three-variable plot is only a limited portion of an infinite diagram.

The case of a perfect gas ($PV = RT$) will be used to illustrate the application of these principles. The following values, which are of suitable magnitude for ordinary gas engine practice, will be used to determine the constant R in the equation: Pressure (P) = 14.6967 pounds per square inch, volume (V) = 100 cubic inches, temperature (T) = 520°.66 Fahrenheit, absolute, corresponding to 60° F., common scale; from which $R = 2.822\ 7$. Taking logarithms, $\log P + \log V = \log R + \log T$, or $1.167\ 220_{(P)} + 2.000\ 000_{(V)} = 0.450\ 666_{(R)} + 2.716\ 554_{(T)}$. In Figure 2, the method of plotting is shown for a single vertical line. In Figure 3, the vertical lines are arranged with log temperatures as abscissæ. Since log R is a known constant, and log T is now shown by the abscissæ, the left hand part of Figure 2 becomes superfluous, and only P and V are given for the verticals hereafter. In Figure 4, instead of giving the actual logarithms, there are given the corresponding natural numbers. The diagram will present no inconvenience to anyone familiar with logarithmic plotting paper or with the slide rule, and no serious difficulty to anyone else, though the crowding of lines representing high values will at first seem peculiar. The use of natural numbers in the diagram obviates the necessity in computations of a double change, from numbers to logarithms and back again.

Since by the construction of the diagram the temperature is constant along a vertical line, *all isothermals* ($PV = P_1V_1$) *are parallel straight lines.*

Referring to Figure 2, it is seen that the algebraic length of the verticals varies proportionally to the logarithm of the temperature. Consequently on Figures 3 and 4, where abscissæ = log temperature, any basal log P line is a straight line, and *all lines of equal pressure* (*isopiestic*, $VT^{-1} = V_1T_1^{-1}$) *are parallel straight lines.*

In Figures 3 and 4, the line AB represents an adiabatic compression from the original volume of 100 cu. in. to a volume of 10 cu. in. The adiabatic is a straight line. This was experimentally proved by taking at random an intermediate volume and calculating its pressure and temperature, with the results given in the following table:

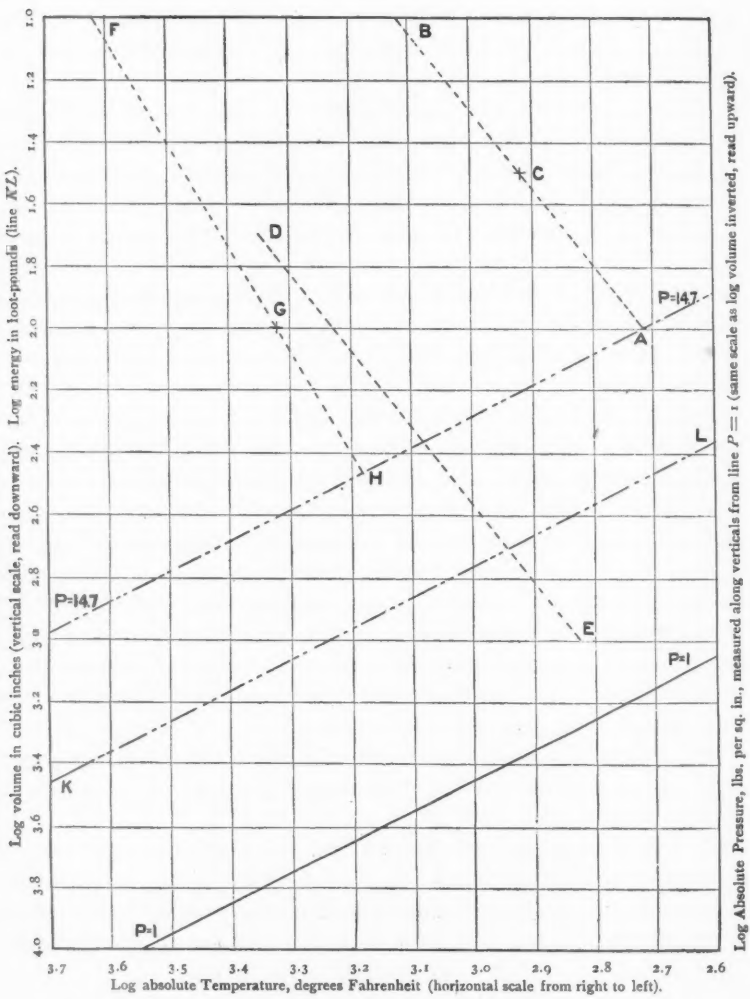

FIG. 3. — PROPERTIES OF A PERFECT GAS; LOGARITHMIC DIAGRAM, LOGARITHMS.

Based on 100 cu. in. at 60° F. and 14.7 lbs. absolute pressure. Adiabatic curves are any straight lines parallel to *AB*. Verticals are isothermals and lines of constant energy. Energy is given by intersections of line *KL* with the verticals read on left-hand scale. (See footnote, p. 281).

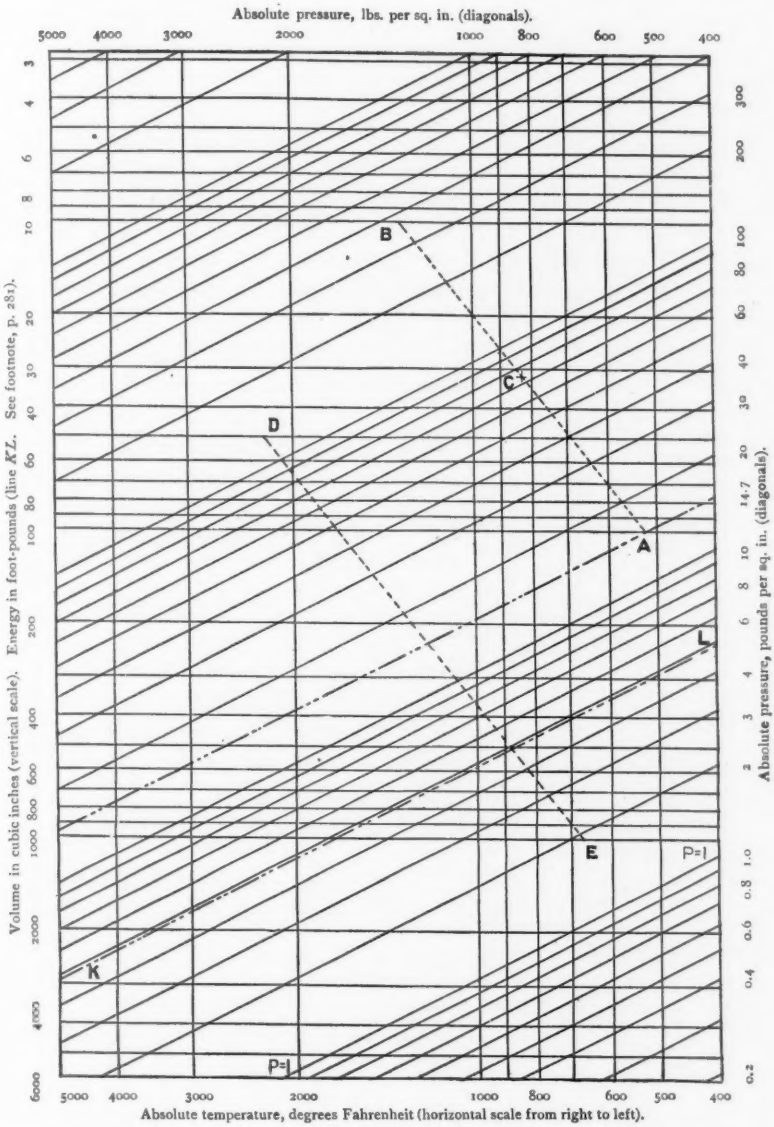
Absolute pressure, lbs. per sq. in. (diagonals).
5000 4000 3000 2000 1000 800 600 500 400
Volume in cubic inches (vertical scale). Energy in foot-pounds (line KZ. See footnote, p. 281).
Absolute pressure, pounds per sq. in. (diagonals).
B
C
D
A
L
E
K
P=1
P=1
Absolute temperature, degrees Fahrenheit (horizontal scale from right to left).

FIG. 4.— PROPERTIES OF A PERFECT GAS; LOGARITHMIC DIAGRAM, NATURAL NUMBERS.

Based on 100 cu. in. at 60° F. and 14.7 lbs. absolute pressure (point *A*).
Adiabatic curves, etc., as in Fig. 3.

Point.	A.	C.	B.
log P	1.167 220	1.869 720	2.572 220
log V	2.000 000	1.500 000	1.000 000
log T	2.716 554	2.919 054	3.121 554

Tangent of line connecting A and $C = \frac{1.500\,000 - 2.000\,000}{2.919\,054 - 2.716\,554} = -2.469\,14.$

Tangent of line connecting C and $B = \frac{1.000\,000 - 1.500\,000}{3.121\,554 - 2.919\,054} = -2.469\,14.$

Now the point C was chosen at random, and the line is shown to have the same direction both sides of it; consequently it has the same direction throughout, and is a straight line.

To find the relation between different adiabatics, the following was chosen at random and computed:

Point.	D.	E.
log P	2.103 879	0.275 932
log V	1.698 970	3 000 000
log T	3.352 183	2.825 266

Tangent of line connecting D and $E = \frac{1\,698\,970 - 3.000\,000}{3.352\,183 - 2\,825\,266} = -2.469\,13,$

i. e., the line DE is parallel to the line AB. But DE is any adiabatic; therefore, *all adiabatics* ($PV^{1.405} = P_1V_1^{1.405}$) *are parallel straight lines.*

In exactly the same manner, it may be shown that any other curves of the form $PV^n = P_1V_1^n$ for any given value of n are parallel straight lines. In Figure 3, the line FGH is a line of the form $PV^{1.3} = P_1V_1^{1.3}$. Another line of the same form passing through A was computed, and had the same tangent.

Accordingly *all the common gas engine diagrams may be represented by straight lines.*

A construction giving the inclination for any required exponential equation of the form $PV^n = P_1V_1^n$ may be derived from the following considerations:

According to Peabody, *Thermodynamics* (1898), p. 69, the exponential equation involving volume (v) and absolute temperature (T) is

$$Tv^{n-1} = T_1v_1^{n-1}, \text{ or } \left(\frac{v}{v_1}\right)^{n-1} = \frac{T_1}{T}.$$

Taking logarithms:

$$n - 1\ (\log v - \log v_1) = \log T_1 - \log T, \text{ or}$$

$$n - 1 = \frac{\log T_1 - \log T}{\log v - \log v_1}.$$

If we consider compressions from $v = 100$ to $v_1 = 10$, the denominator of the above fraction becomes unity, and the equation:

$$n - 1 = \log T_1 - \log T.$$

To apply this construction to Figure 3, let us suppose the inclination is desired of curves for which $n = 1.43$. For point A (volume 100) the log temperature (T) is 2.716 554 2. Add 0.43, and we get log temperature (T_1) 3.146 554 2, corresponding to volume 10. We thus have two points giving the required inclination.

Since entropy is constant along an adiabatic, a scale of entropy may be added to the diagram by drawing a proper series of adiabatics (not done in this paper).

Isothermals are considered also lines of constant energy, and energy considered proportional to the temperature. It is, however, undesirable to confuse the diagram by the addition of a separate scale of energy, and the same end is accomplished by drawing the line KL intersecting the verticals in such positions that the intersections read off on the scale of volumes give *a scale of energy.* Referring to Peabody, *Thermodynamics* (1898), p. 68, the intrinsic energy of a perfect gas,

$$E = \frac{p v}{\kappa - 1} \text{ ft. lbs.},$$

where $p =$ lbs. per sq. ft., and $v =$ cu. ft. This may be altered as follows:

$$E = \frac{p \times 144 \times v}{(1.405 - 1)\ 1728},$$

where $p =$ lbs. per sq. in., and $v =$ cu. in. Then, by the gas law, $pv = RT$,

$$E = \frac{R\,T}{.405 \times 12} = \frac{2.822\ 7}{.405 \times 12}\ T,$$

where for deriving R, $p = 14.7$ lbs. per sq. in., $v = 100$ cu. in., and $T =$ absolute temperature in Fahrenheit degrees. Simplifying, $E =$ 0.580 80 T for that quantity of gas that measures 100 cu. in. at 60° F. and 14.7 lbs. per sq. in. absolute pressure.

While the diagrams so far given apply only to a certain definite amount of gas which is acted upon, acts, and is completely expelled at the end of the cycle, it is the case in practice that a variable clearance

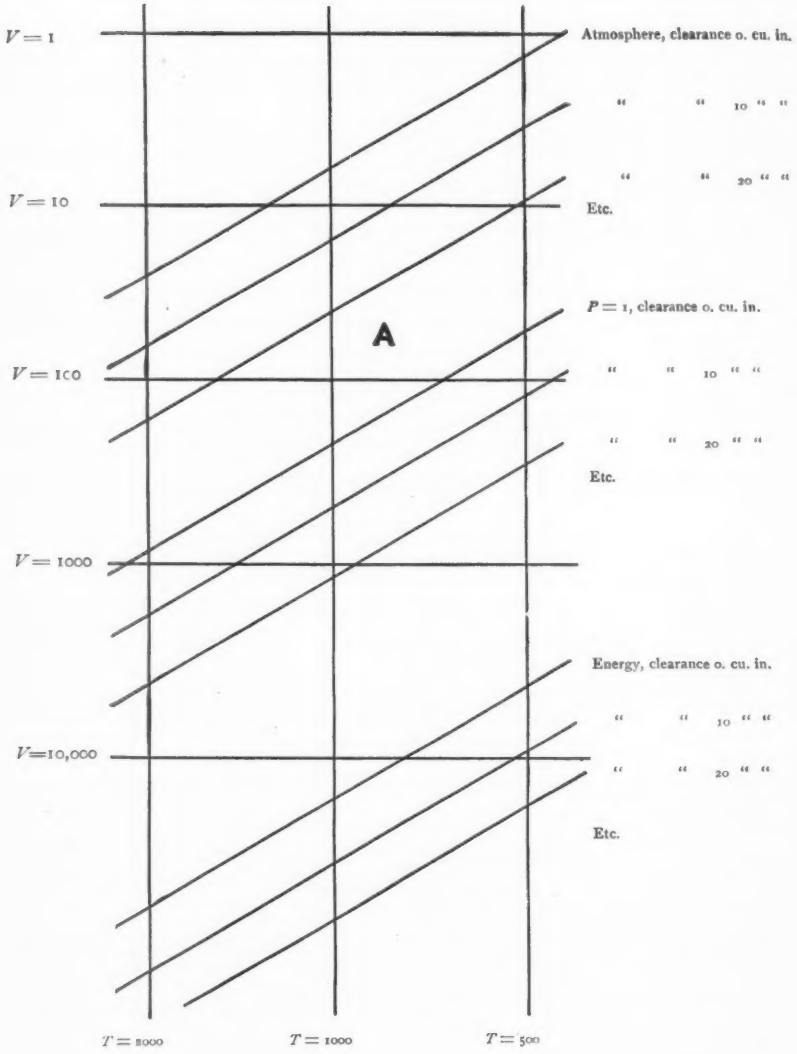

FIG. 5. — DIAGRAM ALLOWING FOR VARIATION IN CLEARANCE.

occupied by an inert gas must also be considered. This may be provided for by a modification of Figure 3 or 4.

Referring to Figure 2, suppose we take an initial volume of 110 cu. in. corresponding to 100 cu. in. piston displacement and 10 cu. in. clearance, the effect will be to increase V and R. On Figures 3 and 4 this might be shown by another $P = 1$ line still lower down on the diagram. The volume and temperature lines would be unchanged, but all the pressure and the energy lines would have to come down, the

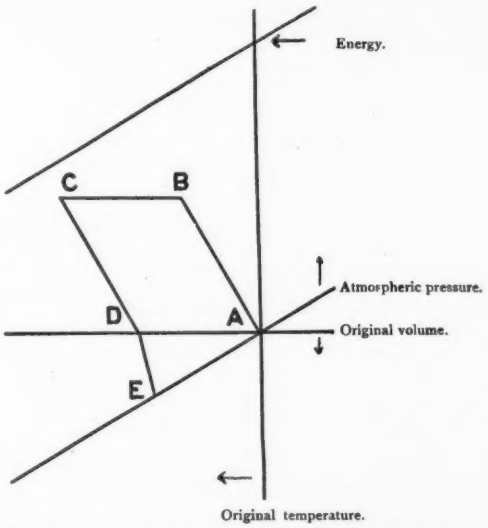

FIG. 6. — DIAGRAM FOR ORDINARY GAS-ENGINE CYCLE.

former an amount equal to the difference between the two $P = 1$ lines. As indicated roughly in Figure 5, a series of $P = 1$, atmospheric, other pressure, and energy lines might be drawn corresponding to convenient clearances. In using such a diagram to find the properties of any point A with a clearance of, say, 10 cu. in., read off volume and temperature as usual, energy from the intersection of A's ordinate with the line *energy, clearance 10 cu. in.*, pressure by taking with dividers the distance along A's ordinate from A to the line $P = 1$, *clearance 10 cu. in.*, then putting one point of the dividers on the line $V = 1$ whereupon the other point will reach down to some volume, say, $V = 9$; then P is 9 for the point A; for P and V are measured to the same logarithmic scale.

Diagrams will now be shown for several types of gas engines, giving the changes of a fixed quantity of gas. The arrows show the directions in which the variables increase in magnitude.

The ordinary cycle, Figure 6: *A*, drawing in of charge, no change of properties. *AB*, moderate compression; temperature, energy, and pressure increase; entropy (measured by distance between adiabatics) varies little or none; volume diminishes. *BC*, ignition; volume con-

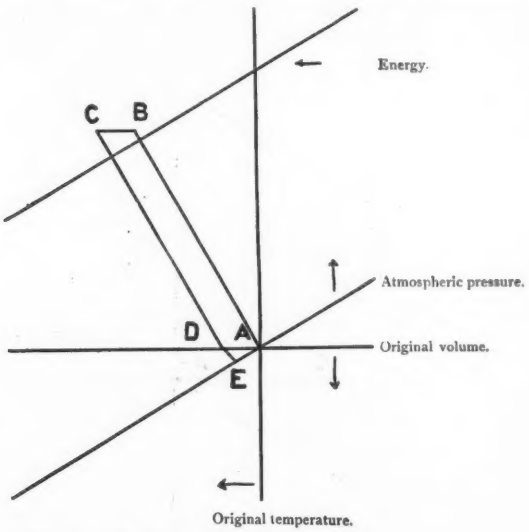

FIG. 7. — THE DIESEL MOTOR DIAGRAM.

stant, pressure, temperature, energy, and entropy increase. *CD*, expansion; entropy varies little or none; volume increases; pressure, energy, and temperature fall. *DE*, adiabatic release into the atmosphere; volume becomes greater than that of the cylinder; *DE* makes an angle with *CD* if *CD* is not an adiabatic; pressure falls to atmospheric; entropy remains constant; energy and temperature fall. *E* removal of waste gases; no change of properties. The energy developed by combustion is the difference between the abscissæ for the vertical lines through *B* and *C*; the energy rejected, minus the original energy of the gas is the difference between *D* and *A*.[1] This is

[1] Energy and temperature, which are considered proportional to each other, are constant along the ordinates. Energy, measured by abscissæ, would be most easily represented by a horizontal scale, but I wished to reserve that means to show temperatures, so drew the line *KL* intersecting volume scale and *undrawn* energy scale *of the same numerical value.*

probably always less than the difference between B and C, since the higher values are closer together in the logarithmic diagram.

It is evident that one aim of gas-engine design should be to get D (release) and A (charge) as close together as possible, and so reduce the energy loss. This is done in the Diesel motor (Figure 7)[1] by extreme compression, the energy imparted by ignition (BC) is not diminished, but owing to its logarithmic position the diagram is narrowed, and D approaches A. With an infinite compression AB and CD would coincide, and all the energy of compression and ignition would be given up in the expansion CD.[2]

Another device is expansion to atmospheric pressure (Figure 8). The difference in energy between F and D is saved; D and E coincide; the energy between E and A is still lost. There is not, as is the case with the Diesel motor, any possibility of complete utilization of the energies of compression and ignition. As the compression is increased with this type, the diagram is narrowed and the gain due to the increased expansion falls off (*i. e.*, the energy abscissæ of F and D approach equality).

[1] The Diesel motor cycle cannot strictly be represented by my diagram; since, after compression the amount of matter in the cylinder is increased by the injection of oil, and my diagram requires a fixed quantity of matter. Figure 7 shows correctly how the high compression of the Diesel motor produces economic results. Compare the *discussion* of a paper by Eddy, "A New Graphical Method of Constructing the Entropy Temperature Diagram of a Gas or Oil Engine from its Indicator Card." (*Trans Am. Soc. Mech. Eng.*, 1900, pp. 275–291.)

[2] To give an illustration of the gain in efficiency from using high compression, the following case has been worked out from a smaller plot than the original of Figure 3, using a 10-inch slide-rule to convert numbers to and from logarithms. Suppose 100 cu. in. gas to be compressed adiabatically to 100, 70, 20, 10, or 0 cu. in., and then to receive an increase in temperature (energy is considered proportional to temperature) of 1,200° F. (a very small value) in each case, and expand adiabatically to original volume. The results would be as tabulated below, and these may be verified in Figure 4.

Remarks.	Volume at compression.	Temperature at Compression.	Same + 1,200° F. = Temperature at Ignition.	Temperature at original volume after expansion.	Difference between original temperature and temperature after expansion.
No compression. No expansion.	100 cu. in.	521	1,721	1,721	1,200
	70	602	1,802	1,561	1,040
	20	1,000	2,200	1,146	625
	10	1,326	2,526	989	468
All energy of compression restored. All energy of combustion utilized.	0	$521 + \infty$	$521 + \infty + 1{,}200$	$521 + \infty + 1{,}200 - \infty - 1{,}200 = 521$	0

An expansion to original temperature (*G*, Figure 8) would indeed utilize all the energies of compression and ignition, but a vacuum-producing device, like the condenser of a steam engine, would hardly give the good results obtained in steam engine practice.

The difference of intrinsic energy of two points on a compression or expansion curve is not a measure of the external mechanical work done by the gas in an engine cylinder in passing from one of the con-

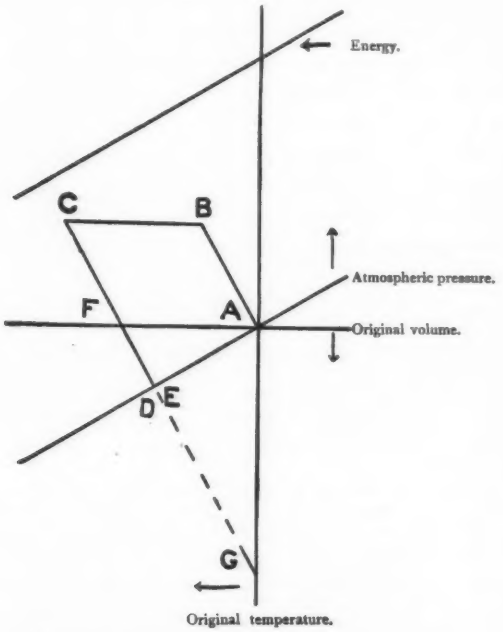

FIG. 8. — DIAGRAM SHOWING COMPLETE EXPANSION.

ditions to the other; for the gas may transform or fail to transform into mechanical work energy received from or lost to the cylinder walls, etc.

A plot about 16 inches square containing the upper part of Figure 4, on a scale of 5 inches = change of 1.000 in log volume, will give with fair precision three significant figures, sufficient for many ordinary purposes. A scale of 10 inches = change of 1.000 in log volume is more easily read and preferable. Ordinary logarithmic plotting

paper of the size 1 — 100 may be used, but I think it better to have the temperatures, as in Figures 3 and 4, at twice the logarithmic scale of the volumes.

Given this plot (Figure 4) and a little careful instruction, a man knowing nothing of algebra, logarithms, calculus, or thermodynamic equations ought, in the opinion of the writer, to be able to figure gas-engine design intelligently. The preceding discussion is not, however, very well adapted to his enlightenment. He needs directions, not derivation.

While this paper has discussed a *logarithmic* three-variable diagram, other functions may be plotted whenever the expressions can be put in the form of three simple quantities whose algebraic sum is a constant, *e.g.*, $\tan a + \log \tan b + pc = k$, etc.

The method of plotting is much better adapted to exhibiting, calculating, or verifying data following known laws, than to deriving formulæ from experimental data. As a method of deriving formulæ, the best thing that suggests itself to me is a soft board and a box of pins, each bearing a label. On each label is put the data corresponding to some one condition experimentally determined. The pins are distributed upon the board in such manner, if possible, that each variable varies continuously. If this succeeds and suggests a formula, the formula may be tested by a plot. The size of the triangle between the lines representing the experimental determination of some one condition is an indication of the variation of the data from the assumed law, and may or may not suggest modification of the same.

Summary.

The tri-axial diagram with rectangular coördinates may be used to plot data of the forms $ma + nb + pc = k$, and $a^m b^n c^p = k$ where m, n, and p are any positive or negative, integral or decimal, real numbers.

For perfect gases, one plot will give with no confusion, pressure, volume, temperature, entropy, and intrinsic energy.

All the lines used in ordinary gas-engine diagrams are straight lines on such a diagram.

A diagram may be made that will allow for the effect of varying clearance.

The conditions for economy from using compression, expansion to atmospheric pressure, and expansion to original temperature are sharply defined, and their mutual relations made apparent.

A man with no knowledge of algebra, logarithms, calculus, or thermodynamic equations can, the writer thinks, by means of the diagram, design gas engines intelligently.

The method may be extended to other than logarithmic functions.

The method can probably be used in deducing formulæ for the results of experimental determinations.

METHOD OF CALIBRATING TURBIDIMETERS.

By GEORGE C. WHIPPLE and DANIEL D. JACKSON.

The Section of Bacteriology and Chemistry of the American Public Health Association at its annual convention, held at Buffalo in September, 1901, adopted the report of progress of the Committee on Standard Methods of Water Analysis. This report included the recognition of the Silica Method as an official standard for estimating the turbidity of water. It does not imply that direct readings upon the silica scale shall be made always, but that, whatever method is used for the measurement of turbidity, the results shall be reduced to this scale and expressed in terms of silica in parts per million. Observations which have been made with the diaphanometer, or turbidimeter, and expressed according to some form of reciprocal scale ought hereafter, if the action of the Section is followed, to be expressed according to the silica standard. Hence, for convenience these instruments should be graduated in parts per million of silica. As the authors have been asked several times to explain the method of calibrating a turbidimeter, it has been thought best to put this explanation into permanent form in order that it may be available for future reference.

The use of the diaphanometer has been described by Hornung,[1] Parmelee and Ellms[2] and by the authors.[3]

The essential parts of the instrument are shown in Figure 1. They consist of a vertical tube for holding the sample, which has opaque sides and bottom, save for an opening at the bottom in the form of a cross, through which light may enter; a standard source of light,

[1] George Hornung: Diaphanometer for Measuring the Transparency of Water. A paper read before the Engineers' Club of Cincinnati, March 19, 1896.

[2] Parmelee and Ellms: On Rapid Methods for the Estimation of the Weight of Suspended Matter in Turbid Waters. Technology Quarterly, Vol. XII, No. 2, June, 1899.

[3] The authors: A Comparative Study of the Methods Used for the Measurement of the Turbidity of Water. Technology Quarterly, Vol. XIII, No. 3, September, 1900.

generally a Wellsbach burner; a condenser; and a reflector for transmitting the light upwards through the tube. The reading is made by pouring the sample into the tube until the cross of light disappears

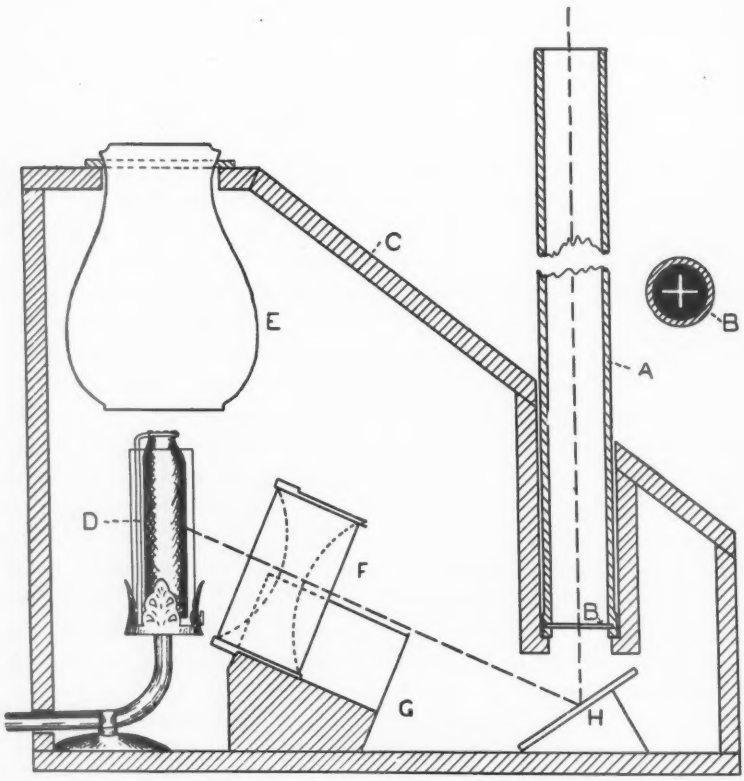

FIG. 1.—CROSS SECTION OF DIAPHANOMETER AS USED BY GEORGE W. FULLER AT CINCINNATI.

A, Tube for holding sample; *B*, Cross of light at bottom of tube; *C*, Case; *D*, Wellsbach burner; *E*, Chimney; *F*, Condenser; *G*, Block supporting condenser; *H*, Reflector.

from view. The depth of liquid in the tube may be obtained by dividing the amount poured in, expressed in cubic centimeters, by the cross section of the tube in square centimeters.

The calibration consists in determining this depth for waters made turbid by the addition of different known amounts of standard

silica, and in compiling from these observations a scale from which future observations of turbidity may be obtained. Inasmuch as local conditions, especially as regards the intensity of the light, are subject to variation, it is necessary to calibrate each instrument under the conditions in which it is to be used. For the method of preparing the silica standard the reader is referred to a previous paper of the authors published in this journal.[1] To calibrate a diaphanometer, or turbidimeter, proceed as follows:

Start with a silica standard of 1000. Pour this into the tube, and at the point where the cross of light becomes obscured measure the amount that has been poured in, or measure the depth of the liquid in the tube. For convenience of description we may consider that the depth may be read directly, which is the case when a removable glass tube inside an opaque tube is used. Repeat the operation several times, each time thoroughly shaking the standard, until the depth has been determined with exactness. Dilute the standard with clear water until it contains but 900 parts of silica per million, and determine the depth at which the cross of light disappears as before. Continue this process, using successive dilutions, until the observations have covered the range of the instrument. The results of these observations may be marked on the tube, or a table may be constructed, giving the turbidity in parts per million of silica corresponding to different depths. Observations which lie between the calibrated points must be obtained by interpolation. The larger the number of observations made, the more accurate will be the scale.

Instead of graduating the instrument directly, however, greater accuracy may be obtained by plotting the observations and drawing a curve which will represent the results, thus avoiding errors of individual observations. Such a curve is shown in Figure 2.[2] The abscissas represent the turbidity of the standard in parts per million of silica; the ordinates represent the depth of liquid in the tube. A calibration table may be made from this curve by reading the turbidities which correspond to various depths, but it is advisable to determine the formula of the curve and calculate these values.

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[1] Technology Quarterly, Vol. XII, No. 4, December, 1899.

[2] It is preferable to use logarythmic cross-section paper for this purpose.

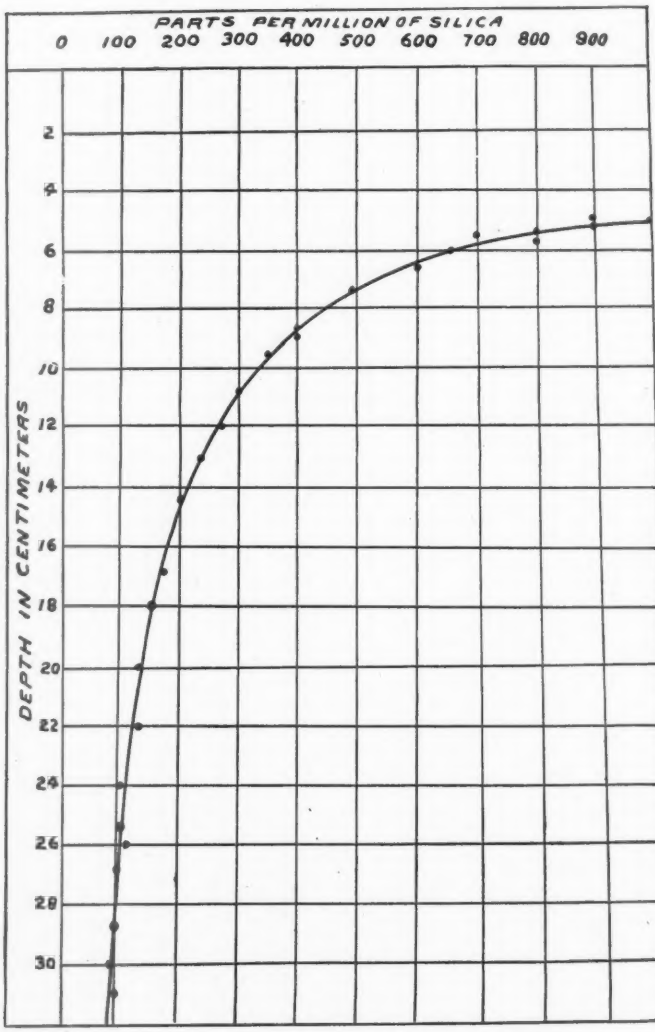

FIG. 2.—EXAMPLE OF THE CALIBRATION OF A TURBIDIMETER, SHOWING THE DEPTH OF LIQUID IN THE TUBE FOR VARIOUS DEGREES OF TURBIDITY.

Experience has shown that the curve may be represented by an equation which has the form of

$$x = \frac{c}{y + a}$$

where x = the turbidity in parts per million of silica,
y = the depth of liquid in the tube, and where
c and a are constants.

The constants are determined as follows: From the plot read the values of x which correspond to certain integral values of y. Thus from the curve shown in Figure 2, we find that

If $y = 5$, $x = 1000$.
If $y = 6$, $x = 650$.
If y = 7, $x = 520$, etc.

Assume for c some value of x, as, for example, 1000; and substitute this and various values of x and y in the general equation, obtaining a series of equations as shown below. From each of these equations calculate the value of a. Thus:—

$$1000 = \frac{1000}{5 + a}, \text{ from which } a = -4.00$$

$$650 = \frac{1000}{6 + a}, \qquad a = -4.46$$

$$450 = \frac{1000}{7 + a}, \qquad a = -5.78$$

$$330 = \frac{1000}{10 + a}, \qquad a = -6.99$$

$$190 = \frac{1000}{15 + a}, \qquad a = -9.74$$

$$130 = \frac{1000}{20 + a}, \qquad a = -12.31$$

Next find the value of a in terms of y by making a second plot, as shown in Figure 3. In this case values of a are plotted as abscissas and values of y as ordinates. These values will ordinarily fall in a straight line over the portion of the scale where the observations can be accurately made. From the illustration[1] given it is evident that

$$a = -\frac{y + 1.8}{1.7}$$

[1] When $a = 10$, $y = 15.5$. As the line cuts the axis of a 1.8 below the axis of y, the slope of the line is shown by the ratio 10 : 15.5 + 1.8, or 10 : 17.3, or approximately 1 : 1.7; hence, $a = -\frac{y + 1.8}{1.7}$.

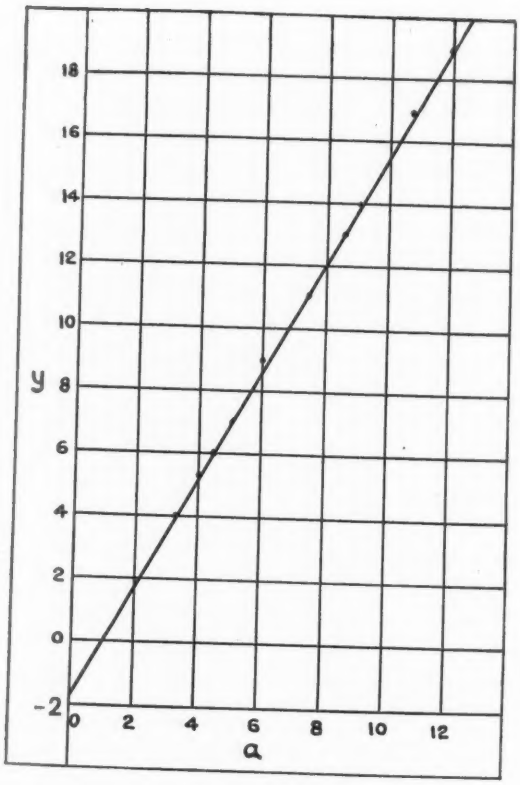

FIG. 3. — PLOT TO FIND THE VALUE OF a IN TERMS OF y.

If this value is substituted in the general equation with c assumed as 1000, we have $x = \frac{1000}{y - \frac{y + 1.8}{1.7}}$, or $x = \frac{2430}{y - 2.6}$ as the equation of the curve.

From this equation it is possible to compute a table giving the turbidity in terms of the silica standard which corresponds to any depth of liquid in the tube when the cross of light disappears.

A new and more convenient form of turbidimeter is described by one of the authors in the *Journal of the American Chemical Society*, November, 1901.[1] This instrument, which is shown in Figure 4, may be used for the determination of the turbidity in water where the turbidity is over 100 on the silica scale. Turbidities of less than 100 are compared directly with the standards in tubes or bottles.

The advantage of this instrument is that standard conditions are used so that the formula for reading is always the same. Consequently a permanent calibration has been made on the instrument, and the turbidity may be read directly in parts per million of silica from the graduation on the tube.

The instrument consists of a tube 25 cm. long and 2.5 cm. in inside diameter, graduated from the bottom upwards in centimeters and millimeters in depth. The tube is also graduated in parts per million of silica according to the formula

$$x = \frac{2485}{y + .75}$$

where x = the parts per million of silica and y = the depth in centimeters at which the image of light disappears.

The following table will facilitate the permanent graduation of the instrument.

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[1] Jackson, D. D.: The Photometric Determination of Sulphates.

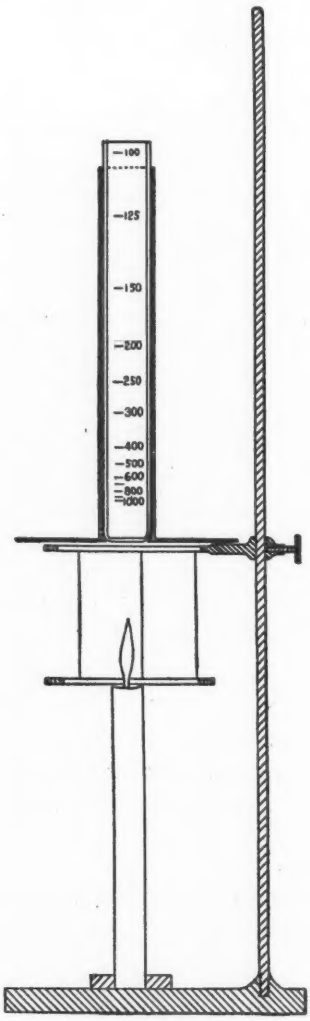

FIG. 4.— SECTION OF THE IMPROVED TURBIDIMETER.

TABLE FOR GRADUATING THE TURBIDIMETER IN PARTS PER MILLION OF SILICA.

Parts per Million of Silica.	Depth in cm.	Parts per Million of Silica.	Depth in cm.
1000	2.3	290	7.5
900	2.6	280	7.8
800	2.9	270	8.1
700	3.2	260	8.4
650	3.5	250	8.7
600	3.8	240	9.1
550	4.1	230	9.5
500	4.5	220	9.9
450	4.9	210	10.3
400	5.5	200	10.9
390	5.6	190	11.4
380	5.8	180	12.0
370	5.9	170	12.7
360	6.1	160	13.5
350	6.3	150	14.4
340	6.4	140	15.4
330	6.6	130	16.6
320	6.8	120	18.0
310	7.0	110	19.6
300	7.3	100	21.5

The glass tube can be slipped into a holder which envelops the sides and is open at the bottom, except for a narrow rim which serves to hold it in place. The bottom of the tube is on a level with the bottom of the holder. A flange 12 cm. in diameter shuts out the stray light of the candle from the eyes. Readings are made in the dark room. A standard candle is used, the top of which is just 3 inches (7.6 cm.) below the bottom of the glass tube when in place for reading.

The instrument is held by an adjustable iron ring. A second ring suspended 3 inches below the first marks the point at which

the top of the candle should come. The candle is lighted and the liquid to be tested for turbidity is then poured into the glass tube until the image of the light just disappears. The reading in parts per million expressed in the silica standard is then taken directly from the glass tube. The bottom of the meniscus should always be taken for the reading.

The simplicity of this instrument and the rapidity with which readings may be made should recommend it above other types of turbidimeters.

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CONTRIBUTIONS FROM THE LABORATORY OF SANITARY CHEMISTRY.

III.

A PORTABLE OUTFIT FOR WATER ANALYSIS.

BY A. G. WOODMAN.

THERE is a constantly increasing demand in water analysis, as in other branches of sanitary science, for more field work. The laboratory for water analysis, though equipped with the best apparatus and in charge of the most skillful analysts, is hampered by restrictions of time and distance. It is not always possible for the mountain to come to Mahomet, and in these cases Mahomet must go to the mountain. There is a large field of usefulness for the laboratory which can be brought directly to the well or river. There is, moreover, oftentimes a considerable saving of expense in making a preliminary survey with simple apparatus before calling into requisition all the paraphernalia needed for final work.

In making preliminary examinations of most likely sources for a town or city supply; in testing the available water supply for a camp, whether of soldiers or pleasure seekers; in the hands of the sanitary engineer, seeking, it may be, to explore and develop our new island possessions; in cases like these the value of a simple, portable outfit will be apparent. The development of the mining interests of the West would have been sadly hampered if the assay laboratory had not been supplemented by the prospector's "kit."

The water analysis kit which is here described has been arranged in the hope that it may prove of use in the service of the prospector for pure water. Cabinets of apparatus and reagents for water analysis are on the market, but what is especially desired is a case which can be made at only slight expense and fitted up from material to be found in every water analysis laboratory. It is not expected that the contents and the arrangement will in every instance be exactly similar

to those of the outfit described, for these will undoubtedly be varied to suit individual preferences as to tests and methods; these are to be taken simply as suggestions in this line.

A general view of the interior of the case, open, and filled with the reagents and apparatus, may be had from the accompanying illustration, reproduced from a photograph. It is made of light wood, $\frac{1}{4}$ inch thick, of the following outside dimensions: 15 inches long, $13\frac{1}{2}$ inches high, $4\frac{1}{4}$ inches deep. The top is hinged so as to turn back, and the front swings outward. The reagent bottles, which are of two sizes, containing 75 c.c. and 100 c.c. respectively, are carried

INTERIOR OF CASE, SHOWING ARRANGEMENT.

on the bottom and on a shelf above. The upmost shelf is divided into compartments for the more convenient storage of small pieces of apparatus. Horizontal wooden strips on the inside of the door serve as a rack for test tubes, and when the door is closed press against the reagent bottles and hold them firmly in place. Nessler tubes are carried horizontally in loops of elastic "webbing" on the inside of the door, and pipettes in the same way on the under side of the top. It is hardly necessary to give the exact dimensions for the interior fittings, since these will vary with the size of the bottles and apparatus. The case is provided with a handle at the top, and is of a convenient shape to carry in the hand. Complete, it weighs about ten pounds. A small wire ring suitable for holding a crucible

or small dish is attached at one side where it can be readily swung out for use, and a clamp for holding a pipette when used as a burette is fastened to the door. Other simple and convenient bits of apparatus will readily suggest themselves.

The following pieces of apparatus are provided:

1 — 10 c.c. pipette graduated in tenths.
1 — 5 " " "
2 — 2 " " hundredths.
25 c.c. calibrated flask.
2½-inch porcelain evaporating dish.
2 — No. 7 porcelain crucibles.
Small drinking cup.
Candle.
2 — Nessler tubes marked at 50 c.c.
6 — Test tubes.
Test tube brush.
Short pieces glass tubing.
Stirring rod.
Burette tip for converting pipette into a burette.
100 c.c. glass-stoppered bottle.

The reagents, which are carried in glass-stoppered bottles, are as follows:

100 c.c. Nessler solution.
" Potassium hydroxide (20 per cent. solution).
" Sulphuric acid (sp. gr. 1.84).
" Acidified silver nitrate.
" Soap solution.
" Potassium permanganate $\left(\text{App. } \frac{N}{100} \text{ solution}\right)$.
75 c.c. Sulphanilic acid.
" Naphtylamine acetate.
" Phenol disulphonic acid.
" Diphenylamine (solid).
" Potassium permanganate (crystals).
" Potassium sulphocyanate (5 grams per liter).
" Hydrochloric acid (sp. gr. 1.12).
" Barium chloride (10 per cent solution).

The preparation of some of the less common reagents in this list will be briefly described.

Nessler Solution. — Dissolve 61.75 grams KI in 250 c.c. distilled water and add a cold saturated solution of $HgCl_2$, which has been made by boiling with an excess of the salt and allowing it to crystallize out. Add the $HgCl_2$ cautiously until a slight permanent red precipitate (HgI_2) appears. Dissolve this precipitate by the addition of 0.75 gram powdered KI. Add 150 grams KOH, dissolved in

250 c.c. of water, make up to a liter, and allow it to settle twenty-four hours. Decant for use. This solution should give a maximum color with ammonia within five minutes.

Sulphanilic Acid.— Dissolve 0.5 gram of sulphanilic acid in 150 c.c. of acetic acid, sp. gr. 1.04.

Naphtylamine Acetate.— Boil 0.1 gram of α-naphtylamine in 20 c.c. of water; filter through a plug of washed absorbent cotton, and add 180 c.c. of acetic acid, sp. gr. 1.04.

Phenol Disulphonic Acid.—Heat together 3 grams synthetic phenol and 37 grams pure, concentrated sulphuric acid in a boiling water-bath for six hours.

Acidified Silver Nitrate.— A 5 per cent. solution of silver nitrate made strongly acid with nitric acid.

Soap Solution.— Dissolve 100 grams of the best white, dry castile soap in a liter of 80 per cent. alcohol. Of this strong solution dilute 75 to 100 c.c. to a liter with 70 per cent. alcohol. Add 70 per cent. alcohol until 14.25 c.c. of the resulting solution gives a lather persisting for five minutes with 50 c.c. of a standard calcium chloride solution (1 c.c. = 0.000200 gram $CaCO_3$).

The tests which can be applied to a water by means of this outfit and the manner of making them are as follows:

(1) *Color.*— Fill a Nessler tube to the mark with the water and observe the depth of color, looking lengthwise of the tube against a piece of white paper. Record as very slight, slightly yellow, light straw, dark brown, etc.

(2) *Free Ammonia.*— Fill a Nessler tube to the mark with the water, drop in about a cubic centimeter of the Nessler solution and after five minutes note the color and record as above. If the water itself has much color, this will interfere and the test should then be made comparative, using two Nessler tubes and Nesslerizing only one.

(3) *Nitrites.*— Fill a test tube half full of the water and with a glass tube add 2 c.c. each of sulphanilic acid and naphtylamine acetate. Observe the color at the end of five minutes.

(4) *Nitrates.*— (*a*) Measure 1 c.c. of the water into a porcelain crucible. Evaporate quickly just to dryness over a candle flame. Add 2 drops of phenol disulphonic acid and then 2 to 3 c.c. of potassium hydroxide solution. The yellow color can be seen when the nitrate amounts to .100 part per million or more. If the yellow color

is very deep, a better idea of the amount of nitrate present may be had from test (*b*).

(*b*) Place in the porcelain dish a bit of diphenylamine the size of a pinhead. Add 10 drops of strong sulphuric acid and mix thoroughly with a glass rod. Let *one* drop of the water fall directly on the acid and note if any blue color appears within one to two minutes. Do not mix after adding the water. The test carried out in this way will show the presence of 2.000 parts per million, or more, of nitrates.

(5) *Chlorine.*— Use 25 c.c. of the water in a test tube and about 1 c.c. of acidified silver nitrate. No appreciable milkiness means less than 5 parts per million; distinct milkiness, 10 parts; clotted precipitate, 40 parts; heavy precipitate, settling readily to the bottom, 100 parts or more.

(6) *Hardness.*— Carry out the test in the usual manner, using 25 c.c. of the water in a 100 c.c. bottle and titrating with the soap solution from a pipette. Values taken from the table which is appended will be fairly close and serve for comparison.

PARTS OF $CaCO_3$ IN 1,000,000 FOR EACH TENTH OF A CUBIC CENTIMETER OF SOAP SOLUTION USED.

C.C.	0.0 c.c.	0.1 c.c.	0.2 c.c.	0.3 c.c.	0.4 c.c.	0.5 c.c.	0.6 c.c.	0.7 c.c.	0.8 c.c.	0.9 c.c.
0.0				0.0	1.6	4.8	7.9	11.1	14.3	16.9
1.0	19.5	22.1	24.7	27.3	29.9	32.5	35.1	37.7	40.3	42.9
2.0	45.7	48.6	51.4	54.3	57.1	60.0	62.9	65.7	68.6	71 4
3.0	74.3	77.1	80.0	82.9	85.7	88.6	91.4	94.3	97.1	100.0
4.0	103.0	106.0	109.0	112.0	115.0	118.0	121.1	124.1	127.1	130.1
5.0	133.1	136.1	139.1	142.1	145.2	148.4	151.6	154 8	157.9	161.1
6.0	164.3	167.5	170.6	173.8	177.0	180.2	183.3	186.5	189.7	192.9
7.0	196.0	199.2	202.4	205.6	208 7	211.9	215.1	218.5	221.8	225.2

(7) *Permanganate Test.*— The solution is approximately $\frac{N}{100}$. The test is carried out in a Nessler tube, using 50 c.c. of the water and adding the solution drop-wise, noting the amount required and the rapidity with which the pink color vanishes. The test carried out in this way can, of course, be considered advisory only.

(8) *Iron.*— This test will be most useful in the case of well waters, to which it may be applied directly without evaporating.

Take 50 c.c. of the water in a Nessler tube, make it distinctly acid with hydrochloric acid and add the $\frac{N}{100}$ permanganate drop by drop, until a faint permanent pink color is produced. Now add 5 c.c. of the potassium sulphocyanate and mix the contents of the tube. A distinct color will be given with .250 or more parts per 1,000,000 of iron.

(9) *Sulphates.* — The usual qualitative test with hydrochloric acid and barium chloride carried out in a test tube.

Before beginning the analytical work take a comprehensive survey of the surroundings of the water — it may render the analysis easier, or even unnecessary; when a luxuriant growth of green algæ is seen around the outlet of a brook into the pond, a shrewd guess as to the quality of the water may be made without the help of a chemical analysis.

In the case of a well — note the proximity of dwellings and outhouses; look for evidences of drains, cesspools, etc.; note the general character and slope of the soil.

In the case of surface waters — note whether the water seems high or low; whether there is much green growth on or in the water; if a pond, examine if necessary the condition of any brooks or feeders. Much may sometimes be learned by following these for a distance.

Finally, a word of caution may be necessary as to the way in which the outfit is to be used. It must be borne clearly in mind that the apparatus is not gotten up for the benefit of the tyro in water analysis, nor does the fact that the outfit is a simple one imply that the subject of water analysis is thereby simplified; as a matter of fact, more experience in analysis and knowledge in interpretation of results is needed for the use of this apparatus than for regular laboratory work.

It is to be regarded simply as an attempt to apply engineering methods to preliminary or isolated problems in connection with water supplies, a subject which is coming more and more into the province of the engineer. Such an attempt would have been impossible in the past, when the training of the engineer left him entirely ignorant of the technique of water analysis and when the data of the chemist and the biologist was to him an unknown language. This is now changed, and the well-trained sanitary engineer of today has a good working

knowledge of the best chemical, biological and bacteriological methods. It is, then, in the hands of such engineers as these, who have had a sound laboratory training, who know quite well what are the limitations of their apparatus and of themselves, that an outfit of this kind will find its greatest usefulness.

Massachusetts Institute of Technology,
Boston, Mass., October, 1901.

CONTRIBUTIONS FROM THE LABORATORY OF SANITARY CHEMISTRY.

IV.

NOTES ON OSCILLARIA PROLIFICA (Greville).

BY ISABEL F. HYAMS AND ELLEN H. RICHARDS.

FIRST PAPER: LIFE HISTORY.

THIS plant, one of the Cyanophyceæ, was first brought under our notice in the course of our work in connection with the systematic examination of the public water supplies of Massachusetts under the auspices of the State Board of Health. One of these supplies was from Jamaica Pond, which is some eighty rods from the residence of one of us. This body of water lies in a suburb of Boston, about four miles west from Dorchester Bay. It is approximately circular, half a mile in diameter; it is much of the shape of an inverted Mexican hat, with a deep pit somewhat out of the centre, between 50 to 60 feet in the deepest part. One-third of the area is, however, less than 10 feet deep. The shores are sandy and pebbly, with no marshy spots. One cove, probably artificially deepened for a boat landing, runs in between two sharp bluffs and is the only approach to a marshy condition. There is the merest brooklet, feeding the pond for a short time in heavy rains and in wet seasons, most of the water coming from springs. Not since the settlement of the region has there been any outlet. The water is of fair quality, and furnished the earliest public water supply of the City of Boston. The Jamaica Pond Aqueduct Company was incorporated in 1795. Forty-five miles of white pine logs, nearly $1\frac{1}{2}$ feet in diameter, with $5\frac{3}{4}$-inch bore, delivered about 400,000 gallons daily as far as Fort Hill. In 1897 some of these pipes were found in good preservation. A portion of Roxbury was supplied with this water until 1893, when the pond became part of the Park System. Analyses of the water will be found in a later paper.

Some half dozen estates, with two stretches of public road and two ice houses, formed the shore of the pond, and the historian, Francis Parkman, made here his beautiful gardens, to which he brought the treasures of the lands he visited.

In the spring of 1886, the smelts, with which the water is usually well stocked, died in great numbers, and while many were raked from the surface, many more fell to the bottom. The next May there was noticed on the water a light brown scum, which soon disappeared; but during the four years following, the growth was such that the whole mass of water was colored, at times a dirty red, and the scum, washing up on the rocks, decomposed with a rich purple color and a disagreeable odor. The year in which the plant was most abundant, it did not entirely disappear during the winter, but was found embedded in the ice which was cut from the water. In other years it disappeared in July, and the water, which in June was so turbid that nothing could be seen at a depth of 12 inches, became clear to 10 feet or more. It is stated that about 1860 something of the same sort occurred. From 1875 to 1886, however, it was not noticeable. Since its appearance in 1887, the pond has never been free from it; in some years it has been worse than in others, dependent upon temperature and sunlight. No other body of water in America has, so far as we know, been so infested.

During the years 1888 to 1892, many samples, not only of the surface water, but of that at various depths, and of ice cut in winter, came into the laboratory. The results of examinations include microscopical records by a trained botanist; but the exigencies of rapid routine work and the changes in the *personnel* of the staff, for various reasons, together with the fact that the use of the pond as a water supply was to be given up on account of the inclusion of the whole region as a part of the Park System of Boston, resulted in rather fragmentary records. The observers by no means agreed among themselves as to the name of this plant, and its life history appeared to be quite unknown.

Our interest was aroused by the mystery surrounding this alga, so peculiar to this pond, so constant in its occurrence, and abundant in quantity as to almost exclude other forms of plant life; and we have made it an object of study during thirteen years.

For the past two years an almost daily record has been kept of the various conditions of its growth and decay, and micro-photographs

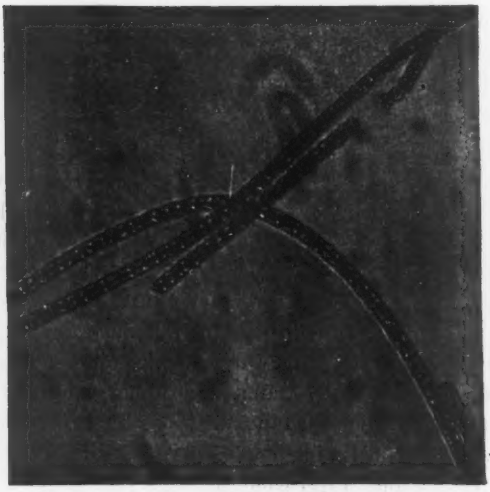

FIG. 1. — OSCILLARIA PROLIFICA. FILAMENTS WITH SHORT COLUMNAR CELLS.

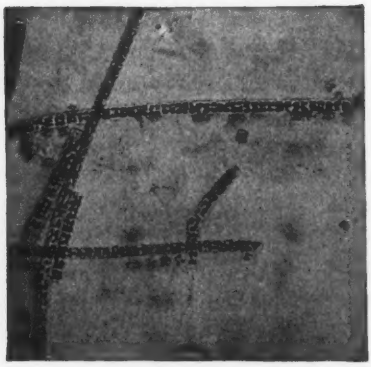

FIG. 2. — SIMILAR TO FIGURE 1. MICROSCOPE FOCUSED TO SHOW THE HIGHLY REFRACTILE BODIES IN THE CELLS.

have been made of the more important phases; so that many points have been determined in its life history, in its chemical composition, and in its relation to the general question of water supply.

We allow the accompanying illustrations (Figures 1, 2, and 3) to serve for the technical botanical description and confine ourselves to the behavior of the plant.

Doubtless the difficulty experienced by earlier observers in identification was due to the great changes in size, color and appearance at different times and to the rarity of spore formation. Constant observation, however, shows the continuity of all phases and renders absolutely certain the identity of the differing forms.

Oscillaria prolifica well deserves its name, since its increase under favoring conditions is marvelous. On a given day no one but a close

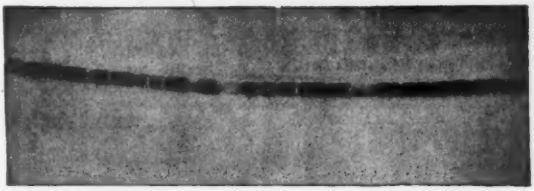

FIG. 3. — OSCILLARIA PROLIFICA. FILAMENTS OF ELONGATED BARREL-SHAPED CELLS, SHOWING TWO CELLS IN PROCESS OF DEGENERATION, AND ONE THAT IS PROBABLY BECOMING A SPORE.

observer would see in the turbidity of the water any indication of the possibilities which within twenty-four hours may give a floating mass of many hogsheads in volume and covering acres in extent. For instance, in 1898 the first "scum" was collected on May 26. On June 11 the water barely appeared turbid in a depth of 1 foot, and only on the margin of the east shore was the fresh growth plainly visible, at 6 P.M. The next day, Sunday, was bright and very warm. Monday morning, at 6 A.M., the water was opaque, and large patches, like red brown cream on a pan of milk, floated in the gentle breeze. The patches were of several square yards in extent, and as the wind freshened they piled up, like Nansen's ice, until the skimmer took up thick clots like rich cream. Several gallons of this cream, nearly pure Oscillaria, was obtained.

The strong wind soon broke up the mass, and cold, cloudy weather followed, so that no more scum was seen; and on June 24 the water

FIG. 4. — FILAMENTS IN THE BROKEN CONDITION.

FIG. 5. — FLOATING MASSES OF OSCILLARIA ON JAMAICA POND, JUNE 12, 1901.

was clear to the depth of 4 to 6 feet, and the only source of specimens was the impure sediment obtained by washing the stones and gravel on which it had settled. At this date the color was green, no longer red brown. A mass of it was dark olive-green, and that which had settled on the stones was broken in short pieces, with peculiar cells on the ends, as if these cells formed a line of weakness. (See Figures 3 and 4.) In the earlier stages of growth the ends of the fila-

FIG. 6. — GATHERING THE SCUM ON JAMAICA POND, JUNE 12, 1901.

ments are blunt pointed like the head of a tape needle. (Figure 1.)

During the time of abundant growth no spores are found, only the long, interlacing threads, forming a thick felt. Figures 5 and 6 show the masses of Oscillaria being driven before the gentle breeze, at 8 o'clock, on June 12, 1901, small patches being visible at least halfway across the pond. On the day before, the "cream" was collected from the opposite shore, the wind having been from the south. Nearly a barrel of the drained substance was collected in

these two days, and one hundred barrels might easily have been obtained. In a week the plant had disappeared from the surface, and the water was clear to a depth of 2 or 3 feet. In each of these thirteen years there have been two days only on which collection could be made of any quantity; on three to five days a slight scum was found. The following table of the years 1900 — 1901 will serve to show the regularity of growth, confirmed by many other observations.

Date. 1900	Temperature of water.	Appearance.	Date. 1901.	Temperature of water.	Temperature of air.
		First sample observed.	April 2	43° F.	43°
April 9	48°	"	April 10	43°	41°
April 24	51°	"	April 24	43°	41°
April 29	53°	"	April 29	49°	60°
		First film seen. Between April 2 and April 24 only three days of sunshine. Film green, not brown.			
May 8	52°		May 8	57°	64°
May 10	51°	Slight scum	May 9	55°	
			May 14	62°	
			May 22	64°	80°
		Slight film	May 26	55°	
		Green scum with brown streaks	June 3	58°	
			June 5 (surface)	73°	
		Abundant growth	June 11 (deeper)	61° 64°	52°
		Abundant growth	June 12	67°	
June 15	70°		June 19	69°	
September 20		Spores. Frothy.	September 22		

Not until the end of August do even occasional spores show themselves. (Figures 7 and 8.) By the middle of September they are not uncommon, but they are never abundant even in October. They

FIG. 7. — PORTION OF FILAMENT OF OSCILLARIA PROLIFICA BEARING A SPORE. Cells barrel-shaped, color bright green. The Spore is lighter in color and more homogeneous in structure than the other cells and is surrounded by a thick, colorless envelope. From living material collected Oct. 19, 1901, and treated on the slide with formaline and iodine. Camera lucida drawing by R. P. Bigelow. ×705.

apparently serve to carry the species through exceptionally severe conditions. For the most part, the plant breaks up into short pieces of two or four divisions, as shown in Figure 4, and thus propagates by segmentation. These fragments become decidedly heavy and rest on the bottom, especially on the stones, at a depth of 2 to 4 feet around the edge of the water. They appear to be suspended in the denser water near the bottom of the shallower portion. They are not abundant in the mud of the bottom at the greatest depth. From which we may say, in general, that *Oscillaria prolifica* lies dormant, either in the form of broken threads of various lengths and various stages of arrested development, or in the form of spores during the winter. That, as spring advances and the surface of the water becomes warmed to a temperature of about 60° F., the plant begins to grow, and continues, so long as food and other conditions last, until the water reaches a temperature of 72°, when rapid breaking up occurs. A week of cool weather in midsummer, as in 1891, will often allow of an increased growth, and a succession of warm days in late October will frequently permit of a fairly vigorous growth along the edges where the water is warm.

Certain chemical considerations will be given in another paper as to the food of the plant.

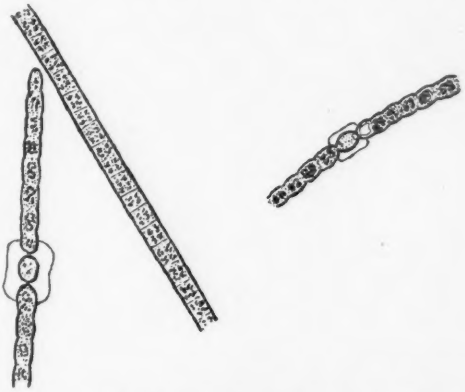

FIG. 8. — OSCILLARIA PROLIFICA. Two filaments bearing Spores as in Figure 7, and part of one filament with short columnar cells, color olive-green. Spores were not observed in filaments in the latter condition. Material same as Figure 7. Camera lucida drawing by R. P. Bigelow. ×765.

The most remarkable variation in color occurs under the varying conditions. At the time of the first observations, 1886 to 1890, the color in early spring and late fall was an ocher yellow to a Bismarck brown. The same shade is observed when an October growth appears. In June, during the period of greatest growth and longest days of sunshine, the whole mass of water, when stirred by the wind, appears a brownish red, sometimes suggesting chocolate, sometimes more like dried blood. On still mornings, after a hot, sunny day, the large patches found floating on the surface, many square yards in extent, are of an orange brown color. These are composed of the new growth of the day before, and soon become distributed into the deeper layers by the wind, or are driven on shore to decay on the rocks, giving to them a rich purple coating, while the surface of the water is covered with a froth, especially around the edges. In July and August, during all these thirteen years, the color has been uniformly green, usually a more or less brilliant blue-green, justifying the right of this species to be classed with the Cyanophyceæ. The pond in some seasons is of a very rich color; in others, as in 1901, a light, dirty green. In the resting stage the color is always blue-green. In short, whenever the plant is found below the surface, it is blue-green in color.

The odor of the growth is a strong grassy odor, not unpleasant; but the odor of decay is intensely disagreeable, fetid rather than putrefactive. In years when the plant is abundant, the odor is evident along the shores of the pond; but, as a rule, it is not distinguishable to any but the experienced nose.

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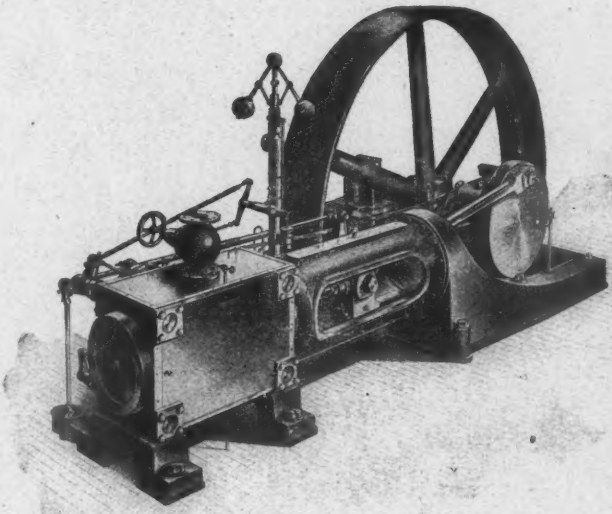

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